Ocean & Coastal Management 115 (2015) 4–9

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Novel methods, new results and science-based solutions to tackle marine debris impacts on wildlife

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ARTICLE INFO

Article history:
Received 21 October 2014
Received in revised form
13 February 2015
Accepted 1 April 2015

Keywords:
ALDFG
Chemical contamination
Marine debris
Litter
Risk analysis

ABSTRACT

There is an exponentially increasing amount of human-associated litter in our oceans. This marine litter results in a wide range of potential impacts on the environment. These range from the introduction of adsorbed polychlorinated biphenyls (PCBs) into food webs to the entanglement and subsequent mortality of threatened seabirds, fish, turtles and mammals in anthropogenic litter and derelict fishing gear. While there has been a major effort afoot to publicize these issues, there remains a paucity of data and scientific research to underpin solutions to the problems. To address knowledge gaps and to identify potential solutions, we assembled thirteen experts from around the world who are leaders in the field. Speakers present current research in three major areas: 1) integrated ecological and oceanographic models to that measure risk to wildlife and predict impact, 2) literature reviews and field studies that measure both the scope and intensity of the threat across species, and 3) analysis of wildlife indicators as regulatory standards for plastic concentration in the environment.

1. Background

Marine litter is an environmental, economic, human health and aesthetic problem. It results in economic losses in excess of hundreds of millions of dollars annually. These losses are associated with reduced tourism revenues, vessel damage, impairments in marine environments, invasives species transport and damage to public health. They also include negative impacts on recreational activities including beach going and fishing. Coastal and marine litter poses a growing threat to marine biodiversity (Vegter et al., 2014), with increasing reports of impacts to individuals, populations, species and ecosystems in the world's oceans and along our shorelines. It poses a complex challenge that has significant implications for marine and coastal environments and human activities around the world.

Most of the litter that ends up in our ocean is lightweight, durable, strong, inexpensive and long-lasting plastic. Annual global production of plastic has risen from 1.5 million tonnes in the 1950s, to 288 million tonnes in 2012; and it is presently doubling approximately every eleven years (PlasticsEurope, 2013). More than six million metric tons of plastic is estimated to enter the ocean each year from land-based sources and this is predicted to increase by an order of magnitude in the next ten years (Jambeck et al., 2015). The total degradation time for plastics in particular is unknown, with estimates in the hundreds of years for many types of consumer products. Thus, litter in the marine environment is a multi-generational problem that extends far beyond the lifespan of the current human population.

To understand the state of knowledge and gain insights into a broad range of ecological impacts resulting from anthropogenic litter, we invited speakers from around the globe to present their latest findings in a symposium that focused on marine debris impacts on wildlife. The symposium featured thirteen speakers who shared results from emerging work on a suite of marine debris research topics, from ingestion and entanglement to the demonstrated chemical impacts of debris. The work presented ranged from a recent literature review that summarized the state of knowledge to multiple risk analysis approaches, including expert elicitation, experimental studies, and risk modelling. Recent research was also presented that focused on threats posed by debris to focal taxa (turtles, seabirds and marine mammals) and evaluated the efficacy and influence of waste management policies on coastal debris. Researchers also shared findings on approaches to monitoring marine debris at sea, the density of marine litter on

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http://dx.doi.org/10.1016/j.ocecoaman.2015.04.004

seamounts, and derelict gear impacts on marine fauna. Species and fisheries-specific examples highlighted some success stories and monitoring approaches that achieve ecological quality targets and reduce impacts to biodiversity through implementation of litter and gear removal efforts.

2. Problem scope, risk framework and risk assessments for protected species

Just over a decade ago, the number of marine species known to be impacted by anthropogenic litter was estimated at around 260 species (Derraik, 2002). Now, the number of marine species with reports of fatal entanglement in and ingestion of marine debris has risen to nearly 700, and continues to increase (Gall and Thompson, 2015). A recent review of 340 publications on encounters and impacts between marine debris and marine animals described the current state of knowledge on the effects of anthropogenic debris on marine and coastal species (updated from STAP, 2011; Secretariat of the Convention on Biological Diversity and the Scientific Advisory Panel – GEF, 2012). Plastic debris accounted for over 90% of encounters between debris and wildlife, with microplastics (defined as items <5 mm) noted in 10% of ingestion reports. Both indirect and direct consequences of wildlife-debris encounters are increasing, though there is still little published information on population-level and/or sub-lethal consequences of debris interaction (but see Rochman et al., 2013, 2014a,b; this paper). While direct harm or death has been reported for far more entanglement encounters (79%) than ingestion encounters (4%), ingestion may pose substantial lethal and sub-lethal impacts for individuals. Furthermore, a minimum estimate of 17% of species on the IUCN Red List known to known to encounter debris either via entanglement, ingestion or both are currently listed as threatened or near-threatened. This work has since been further updated, with 340 original publications reporting encounters between debris and individuals for 693 species (Gall and Thompson, 2015).

As we see an increase in marine species interacting with wildlife, identifying the potential impacts of litter on major marine taxa provides a potentially useful lever for change. From more than 200 million debris items removed and identified over nearly 30 years of International Coastal Cleanup events, the most common 20 litter items in Ocean Conservancy's global database have been identified. Expert elicitation was used to assess the relative ecological threat or risk each of these litter items poses to animals in the marine environment. More than 80 respondents from sectors ranging from scientific organizations and non-governmental organizations to volunteers assessed the entanglement, physical ingestion and chemical contamination threat that each of the top 20 debris items poses to seabirds, turtles and marine mammals. Experts rated fishing nets and gear, balloons, plastic bags, plastic beverage bottle caps, and plastic utensils as the litter items most harmful to wildlife. The results provide support for the implementation of plastic bag bans and bottle deposits that are already underway in some areas. The findings also provide a means of identifying those items that experts rank as litter that is most likely to result in harm to key marine taxa. However, the need to implement large-scale solutions to reduce the input of plastic litter into the marine environment cannot be overlooked.

Another means of evaluating the risk anthropogenic litter poses to wildlife is to combine empirical data and models to predict areas of risk to marine taxa. Scientists have been applying a risk framework to predict the scale and extent of risk to seabirds and turtles at both regional and global scales (Schuyler et al., 2013; Wilcox et al., 2014; Wilcox et al. submitted for publication). To understand the threat marine debris poses to wildlife, researchers combined published literature with empirical information and modelling to predict the highest areas of risk for nearly 200 of the world's seabird species. A global-scale particle-tracking model was used to predict the distribution of floating litter in the ocean, based upon coastal human population density around the world (sensu van Sebille et al., 2012). The oceanic litter distribution was then overlaid with the distribution of seabird taxa to evaluate the exposure of each species to debris, based upon spatial overlap between marine litter and individual seabird species. Comparing estimates of exposure to published seabird diet studies provided an empirical comparison to allow evaluation of the reliability of exposure as a predictor of debris ingestion. While exposure to plastic was a significant predictor of debris ingestion, body size and foraging strategy are also important predictors. Based upon empirical evidence and model predictions, areas of highest risk are not in the northern hemisphere's gyres as may be predicted based upon litter density and the awareness of ocean 'garbage patches', but instead are along the northern boundary of the southern ocean where seabird species richness is particularly high.Approach can be used to provide a hierarchical list of species likely to be heavily impacted based on their ecological characteristics, along with a global map of expected impacts from various anthropogenic stressors.

Following on the risk framework approach used to evaluate threats to seabirds, researchers applied a global risk model to identify the factors that are most influential in determining the probability of a sea turtle ingesting debris. The model used incorporated debris distribution maps based on ocean drifter data, sea turtle habitat maps, and field necropsies for validation. It also used multiple measures of debris encounter rates, life history stage, species of turtle, and date of stranding. Life history stage was the best predictor of debris ingestion (young oceanic turtles are more likely to ingest debris than are older coastal feeding turtles), but the best-fit model also incorporated the species and plastic exposure within a limited distance (250 km) and time from stranding observation (one year). Olive ridley turtles (Lepidochelys olivacea) are at the highest risk of debris ingestion and Kemp's ridley turtles (Lepidochelys kempii) are at the lowest risk of debris ingestion. In contrast to findings of turtle entanglement risk, encounter rates between turtles and debris is not the sole predictor of debris ingestion, suggesting that selectivity plays a more important role in ingestion rates than entanglement rates. Importantly, ingestion rates for sea turtles have increased significantly through time, with increased rates of plastics ingestion reported in some species of sea turtles in particular (e.g. green and leatherbacks [*Chelonas mydas* and *Dermochyls coriacea*, respectively]; see Schuyler et al., 2012, 2013).

While debris is often reported from along our coastlines and floating on the ocean's surface, far less is known about the abundance and distribution of the debris that sinks to the ocean floor. To understand the full spatial extent over which we find human-made refuse, researchers have been exploring the deep sea (at 200 m and beyond). Remote cameras, aiming to document deep marine fauna, observed everything from 18th century clay pots to wine bottles, derelict fishing gear, electronics and plastic rubbish, at densities up to 17.4 items per hectare (Woodall et al.). Litter on the ocean floor was ubiquitous, but patchy and highly variable between seamounts. In the southwest Indian Ocean, derelict fishing gear was the most abundant type of litter observed. Skeletal remains of numerous species of wildlife were found with this derelict gear in the deep sea, implicating the gear as a potential mortality source. Similar to findings of coastal litter, plastic was the most common material type for items found during these deep sea surveys. This work demonstrates that the abundance, material type and most likely source of submerged litter is likely linked with local activities such as shipping and fishing.

In addition to contributing to the sunken litter found on